4. ANALYSIS METHODS

Two types of instruments were used to obtain data during the program. The principal one was the imaging spectrometer described in the previous section. In addition a series of balloonborne radiosondes were used in connection with one data set. Analysis methods used in connection with these instruments are described below.

4.1 Imaging Spectrometer Analysis Method

The most valuable data set using this instrument would be to take a series of measurements with the aircraft flying at fixed altitudes beginning 3 km beneath the nominal or expected height of the tropopause. Even if the tropopause is found to lie as much as 3 km higher than expected, these measurements would yield the mean water substance content and relative humidity through the range of altitudes of most critical importance for verification and refinement of global climate models.[2,4] On rare occasions when the tropopause is found to lie more than 3 km higher than expected, measurements may also be taken at one or two higher altitudes (i.e., a maximum of 7-8 sampled altitudes at intervals of 1.5 km). Since the WB-57F aircraft has a maximum altitude of ~ 21 km, which is ~ 4 km above the mean height of the tropopause in the tropics, it will generally be possible to obtain measurements at a minimum of two fixed altitudes above the tropopause. Continuous data sampling during aircraft ascent and descent will also yield very useful data; since ~ 6 seconds of data are required to obtain sufficient signal-to-noise for a usable measurement, we plan to fix the rate of ascent and descent at 0.5 km per minute, yielding differential column density measurements in altitude increments of ~ 50 m. In effect, we will thus be able to measure volume densities with a vertical resolution of as little as ~ 50 m. To prevent the traversal of undesirably large horizontal distances, the aircraft will undergo a 180° turn after every fixed-altitude measurement, keeping the maximum horizontal range of each measurement sequence to within ~ 70 km. Background calibration measurements, with the ARES instrumentation pointed away from the Sun or Moon, will be taken during the turns. Each measurement sequence will take ~ 40 minutes to complete and will thereby reduce the effective horizontal range of the aircraft by ~ 600 k m.

The measurement at the highest of the fixed altitudes will also provide a determination of the total column density of water substance above this altitude. Such data will be of substantial value in

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advancing our understanding of the chemical reactions that occur in the stratosphere; in particular, these measurements will shed new light on the formation of cirrus at very high altitudes and, indirectly, on the destruction of stratospheric ozone by fluorocarbons, since this destruction has been found to be mediated by high-altitude ice crystals.

Numerical experiments that we have performed with MODTRAN[8] indicate that at an altitude of 10 km, diffuse atmospheric emission, at characteristic wavelengths within the range of the ARES instrumentation, varies from 1×10^{-7} W cm^{-2} sr^{-1} µm^{-1} for clear air, to 6×10^{-7} W cm-^{2} sr^{-1} µm^{-1} in the presence of an overlying cirrus deck with a thickness of 0.1 km, an to 1×10^{-5} W cm^{-2} sr^{-1} µm^{-1} in the presence of a 0.2 km thick cirrus deck. An improved theoretical understanding of the nature of the emission will determine whether measurements of such emission can be used to infer the overlying column density of condensed water.

The solar irradiance at altitude Z is

$$I(Z) \ = \ I_s \ T_x \ (Z) \ , \tag{1}$$

where

I_s = solar intensity, assumed constant over spectral bandpass, and

$T_x(Z)$ = transmittance, a function of absorption coefficient and water density.

For a single absorber (e.g., H_2O) and weak absorption ($T_x \cong 1$), i.e., high altitude,

$$Ln \ \frac{I(Z_1)}{I(Z_2)} \ = \ Ln \ \frac{T_x(Z_1)}{T_x(Z_2)} \ = \ \sigma \int_{Z_2}^{Z_1} ndz. \tag{2}$$

If σ is known, i.e., if temperature and pressure are measured, we can obtain the density between Z_1 and Z_2. From MODTRAN[8] we can calculate the same ratio for the model measured, temperature, and specified water vapor density. Then the ARES-measured water vapor density can be determined.

The method is to proceed down from the highest altitude, measuring one spectral band at a time, then determine the water vapor density from each band and average the water vapor profiles over all bands.

4.2 Radiosonde Analysis Methods

In connection with one set of ARES measurements, four radiosondes were launched. The sondes were manufactured by Vaisala (Model RS-80L) and have an extended temperature range for relative humidity measurements. The sondes measure pressure (1060 to 3 hPa), temperature (+60° to -90°C), and relative humidity (0 to 100% RH). The accuracies of the measurements are ± 0.5 hPa in pressure, ± 0.2°C in temperature, and ±2% RH in relative humidity. It is worth emphasizing that the accuracy of the relative humidity measurement is an absolute error in relative humidity, not a relative error. That is, at low relative humidity, the relative uncertainty in the measurement will be quite large. The relative humidity sensor has an extended temperature range (to -60°C) compared to the standard sonde which measures relative humidity reliably only to -40°C. There is a lag time of one second in all the measurements, which, with the typical ascent rate of 5 m sec^{-1}, introduces a small uncertainty in the altitude profile.

The local H_2O density $[H_2O]$ is determined directly from the relative humidity and the ambient temperature ("dry-bulb temperature") by the following equation:

$$[H_2O] \; = \; \frac{P_{vapor}(T_{ambient}) \cdot R.H.}{R \; T_{ambient}} \; , \qquad\qquad \textbf{(3)}$$

where P_{vapor} is the equilibrium vapor pressure of water at the ambient temperature $T_{ambient}$, R.H. is the relative humidity, and R is the ideal gas constant.